

The effect of carbohydrate mouth rinsing on skill-specific fencing performance and cognitive function following a fatigue-inducing bout of fencing

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Abstract

The aim of this study was to investigate whether rinsing the mouth with a carbohydrate solution could improve skill-specific fencing performance and cognitive function following a fatigue inducing simulated bout of fencing in epee fencers. Eleven healthy, competitive epee fencers (three female; eight male; 33.9 ± 14.7 years; body mass 79 ± 16 kg; height 162 ± 54 cm) volunteered to participate in a single-blind crossover design study. During visit 1 participants completed a 1-minute lunge test and stroop test pre and post fatigue inducing fencing protocol. A 30 second electroencephalography (EEG) recording was taken pre-protocol participants were instructed stay in a seated stationary position with their eyes closed. Heart rate and ratings of perceived exertion were recorded following each fight during the fatiguing protocol. Participants mouth rinsed (10 seconds) either 25ml of a 6.7% maltodextrin solution (CHO) or 25ml of water (placebo) between fights and during the EEG recording. Blood lactate and glucose measurements were taken at baseline, pre and post protocol. All measurements and tests were repeated during a 2nd visit to the laboratory, except participants were given a different solution to mouth rinse, separated by a minimum of 5 days. The results showed an increase in heart rate ($P < 0.05$) and overall RPE ($P < 0.001$) over time in both trials. There were no recorded differences in blood glucose ($F(1,8) = 0.634$, $P = 0.4$, $\eta^2p 0.07$) or blood lactate levels ($F(1,8) = 0.123$, $P = 0.7$, $\eta^2p 0.01$) between trials. There was a significant improvement in lunge test accuracy in the CHO trial ($F(1,8) = 5.214$, $P = 0.05$, $\eta^2p 0.40$). However, there was no recorded difference in response time to congruent ($F(1,8) = 0.326$, $P = 0.58$, $\eta^2p 0.04$) or incongruent ($F(1,8) = 0.189$, $P = 0.68$, $\eta^2p 0.02$) stimuli between trials. In conclusion mouth rinsing a CHO solution significantly improves accuracy of skill-specific fencing performance but does not affect cognitive function following a fatigue inducing fencing protocol in epee fencers.

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Chapter 1 Introduction

The ergogenic effect of carbohydrate (CHO) supplementation during endurance sport has been well documented within the scientific literature (Bergstrom et al, 1967; Black et al, 2012; Hargreaves, Hawley, and Jeukendrup 2004; Jeukendrup 2004; Schabert et al., 1999; Sherman et al., 1989; Wright et al., 1991). Christensen and Hansen (1939) highlighted the importance of CHO as a fuel substrate in a series of respiratory exchange studies. These results were supported by Bergstrom et al. (1967) who took muscle biopsies to measure muscle glycogen levels following a range of dietary and exercise interventions. Since then a substantial number of studies have focused on nutritional strategies to maximise endogenous CHO stores and minimise CHO depletion throughout exercise (Currell and Jeukendrup, 2008).

1.1. The effect of CHO ingestion on high intensity and intermittent exercise

The availability of CHO as a substrate for muscles and the central nervous system has not only been identified as a limiting factor for endurance performance it has also been linked to high intensity and intermittent exercise (Burke et al., 2001). A number of studies have reported improvements in sports performance lasting ~1 hour following the ingestion of CHO (Davison et al., 2008; El-Sayed, Balmer and Rattu 1997; Jeukendrup et al, 1997; Nicholas et al., 1999; Maughen and Poole, 1981). Moreover recent research investigating the ergogenic effect of CHO ingestion during sports requiring high levels of motor and cognitive skill, such as squash and football, have found evidence to support improvements in skill-specific tasks (Bottoms, Hunter and Galloway, 2007; McRae and Galloway, 2012). However, currently the mechanisms to explain such performance improvements associated with CHO ingestion during exercise lasting ~1 hour and intermittent exercise remains elusive.

The mechanisms of CHO supplementation are complex. Nevertheless, two primary mechanisms have emerged within the literature. Firstly the direct influence on CHO oxidation rates during prolonged exercise (>2 hours) where skeletal muscle and liver glycogen stores are a limiting factor (Cermack and Loon, 2013). However as only 5-15g of exogenous CHO is oxidised during the 1st hour of exercise (Juekendrup et al., 1997) it is unlikely such metabolic mechanisms explain the performance benefits reported during exercise lasting ~ 1 hour and intermittent exercise. Therefore during shorter, high-intensity, exercise (<1 hr.) the underlying mechanism has been attributed to a central nervous system response to exposure to CHO within the oral cavity (Carter, Juekendrup and Jones, 2004b; Chambers, Bridge and Jones, 2009). Although the specific receptors within the mouth are yet to be identified, there have been a growing number of studies, which have supported this hypotheses using a mouth rinsing protocol.

1.2. The effect of carbohydrate mouth rinsing on performance and the underlying mechanisms

Carter, et al. (2004a) were the first to establish a performance effect of CHO independent of blood glucose levels. They found when glucose was administered via infusion 40km cycle time trial performance was not significantly improved despite an abundance of glucose in the blood stream. However a performance effect was established without ingesting CHO, indicating a central nervous system response (Carter, et al., 2004a.).

Carter, Jeukendrup and Jones, (2004b) tested their initial findings in a subsequent study whereby participants rinsed a CHO solution in their mouth before spitting it out, which is currently referred to as carbohydrate mouth rinsing (CMR). The researchers found

cycling time trial (TT) performance was significantly improved following multiple CMR compared to a taste-matched placebo mouth rinse (Carter et al., 2004b). Consequently a growing number of articles, mainly within cycling, have demonstrated that CMR improves sport performance lasting ~1 hour (Chambers et al., 2009; Fares et al., 2011; Lane et al., 2013; Mündel and Jones, 2010; Phillips et al., 2014; Pottier et al., 2010; Rollo et al., 2008; Rollo et al., 2010; Sinclair et al., 2014). In a recent meta-analysis pooled from several eligible cycling studies the mean improvement in power output following CMR was ~5 W (95% CI = 0.9-9 W), which is significant both statistically and as an outcome in sporting events (de Ataide e Silva et al., 2014).

In addition there have been a handful of studies that have investigated the mechanisms controlling the influence of CMR on physical and cognitive performance in sport and exercise. Chambers, Bridge and Jones, (2009) were the first to investigate the mechanisms of CMR using functional magnetic resonance imaging (fMRI) scans to identify the regions of the brain activated following a glucose or maltodextrin (MALT) mouth rinse. Interestingly both glucose and MALT activated the Orbitofrontal Cortex and Dorsolateral Prefrontal Cortex, despite differences in sweetness. The authors concluded CMR produces a central neural response independent of sweetness (Chambers, Bridge and Jones, 2009). It is possible the results could be attributed to the calorific content rather than the sweetness, although further research is needed to confirm this hypothesis.

The findings by Chambers, Bridge and Jones (2009) have been partially supported by a recent study using electroencephalography (EEG) to measure the activation of the brain (De Pauw et al., 2015). The researchers also found activation within the Orbitofrontal Cortex following a CMR whilst the participant remained inactive. Both studies provide

preliminary support for a central processing hypothesis and highlight an effect of CMR on regions of reward and motivation in the brain. However to our knowledge there is currently no research investigating the interaction between CMR and the brain within a sporting context.

1.3. Potential Limitations of CMR

Despite the fact that there is seemingly robust evidence providing support for the positive effect of CMR on sport performance, a number of studies have failed to find significant results (Beelen et al., 2009; Che Muhamed et al., 2014; Chong, Geulfi and Fournier, 2011; Rollo, Williams and Nevill, 2011; Witham and Mckinnay, 2007). For example Chong, Geulfi and Fournier (2011) found no significant performance effect following CMR on maximal sprint performance. Likewise a number of very recent studies have found conflicting results on skill maintenance and performance in intermittent sport (Clarke, Kornolios and Richardson, 2015; Ispoglou et al; 2015; Přibyslavská et al., 2015). The magnitude and direction of findings could be attributed to a range of variables, including the duration and frequency of mouth exposure (Sinclair et al., 2014), training status of subjects, mode and intensity of exercise, and the nutritional status of subjects (Fares and Kayser, 2011; Lane et al., 2013). Therefore the effect of CMR on intermittent skill-based sports, such as fencing, remains unclear.

1.4. Indicators of fencing performance

Fencing is an open-skilled Olympic and Para-Olympic combat sport, characterised by short bursts of high intensity exercise followed by periods of rest. While there has been very little research investigating variables affecting fencing performance, it has been established that maintaining one's psychological condition, including visual perception and attention, delays the onset of fatigue and thus improves subsequent performance

(Hijazi, 2013). Moreover findings from other skill-based intermittent sports, such as cycling and squash, have highlighted the attenuating effect of fatigue on skill maintenance (Davey, Thorpe, & Williams, 2002; Hornery et al., 2007; Murray, et al., 2001; Royal et al., 2006; Vergauwen et al., 1998). Therefore it could be speculated that delaying the onset of fatigue could improve a fencer's psychological and physiological condition, thus improving performance. CHO ingestion during intermittent sport has been reported to improve performance. Furthermore CMR is emerging within a number of review articles as the optimal CHO supplementation strategy during intermittent high intensity exercise (Stellingwerff and Cox, 2014; Jeukendrup, 2013). Due to the work/rest ratios during a typical fencing competition CMR would be a practical strategy for fencers to adopt. In competition each poule fight lasts for a maximum of 3 minutes followed by a rest period of 6 minutes, allowing ample time for fencers to mouth rinse in between fights without effecting their recovery. Also expectorating the CHO between fights would avoid too much fluid in the stomach during fights, which could have an adverse effect on performance. Therefore it would be beneficial to investigate whether CMR can improve skill-specific performance and cognitive function following a fatigue inducing fencing protocol.

1.5. The importance of CMR within a practical setting

Improving our knowledge of the effects of CMR on physical and cognitive performance would enhance the current understanding of CHO supplementation during high intensity sport (<1 hour). It would also provide a successful alternative nutritional strategy for athletes who experience gastrointestinal (GI) discomfort or for athletes following a calorie-restricted diet. GI distress is commonplace amongst athletes with an estimated 20-50% experiencing symptoms during a sporting event (Stuempfle and Hoffman, 2015, van Nieuwenhoven et al., 2004). The consequences for an athlete experiencing

GI distress include nausea, heartburn, vomiting, abdominal cramps, bloating and diarrhoea (Peters et al., 1991) which will likely serve to impair overall sporting performance. One reason athletes experience GI discomfort during sport is due to high Carbohydrate (CHO) ingestion. However CMR eliminates the needs to ingest CHO and reduces stress on the gut, therefore eliminating GI distress. Although GI distress commonly occurs during endurance events, it is important to acknowledge some athletes have clinical conditions, which impairs their ability to digest CHO effectively.

The present study aims to further the current knowledge of CMR by testing whether CMR can significantly improve skill maintenance and cognitive function in epee fencers following a fatigue inducing protocol. The study will additionally measure activation of regions within the brain whilst CMR in a sport specific environment, in order to expand on the findings of previous research. The present study, hypothesises that mouth rinsing with a CHO solution will improve skill-specific performance and cognitive function following a fatigue inducing fencing protocol. In addition mouth rinsing with a CHO solution will activate regions of the brain associated with reward and motivation.

Chapter 2. Literature Review

Over the past decade one of the interesting sport nutrition topics to emerge from the scientific literature is the enhancing effect of carbohydrate (CHO) without the need for ingestion on sports performance. Carbohydrate mouth rinsing (CMR) is where a CHO solution, either glucose or maltodextrin (MALT) is swilled around the oral cavity for an extended period of time, typically 5-10 seconds, before it is expectorated. Although a number of research studies have observed an increased capacity to maintain performance during moderate and high intensity exercise lasting around 1 hour following CHO supplementation it has been reported that CHO does not serve as a substantial muscle substrate during the first hour of exercise. Therefore the mechanism could be attributed to a neural response. Consequently researchers have found that by simply exposing receptors in the oral cavity to either glucose MALT, regions of reward and motivation are stimulated within the brain and subsequently work outputs were increased (Chambers, Bridge and Jones, 2009). The following discussion will review the current literature on CHO supplementation focusing in particular on our current understanding of CMR.

2.1. CHO Supplementation and Sports Performance

The first recorded evidence of CHO as an important fuel for exercise dates back to the early 1900s (Krogh and Lindhard, 1920). In a later study Christenson and Hansen (1939) discovered CHO utilisation during exercise could be influenced by diet, and subsequently exercise tolerance could be improved. The initial findings of the early 1900s was later supported by a muscle biopsy study which examined the effect of various nutritional strategies on performance and found muscle glycogen stores to play a significant role in sport performance (Bergstrom and Hultman, 1969). Since this early work a plethora of articles have been published exploring the implementation and

resultant effect of a variety of CHO supplementation strategies during high-intensity sports (< 1 hour) and endurance events (>2 hours). In a recent meta-analysis compiled from 61 studies 82% found significant performance benefits following CHO supplementation (Stellingwerff and Cox, 2014). It is therefore not surprising CHO supplementation is frequently used by athletes to enhance performance within their respective sports.

2.1.1. The performance benefit of CHO supplementation during endurance exercise

There is sound evidence to support an increase in endurance performance when CHO is ingested in direct comparison to water (Angus et al., 2000; Carter et al., 2003; Currell and Jeukendrup, 2008; Langenfield et al., 1994; and O'Brien et al., 2013; Smith et al., 2010, 2013; Watson et al., 2012). Moreover the performance effect size has been linked to the composition and administration of CHO supplementation (Vandenbogaerde and Hopkins, 2011). This body of work has fuelled an emerging trend to explore the added benefits of multi-transportable CHO, for example a blend of glucose and fructose, on endurance performance (Currell and Jeukendrup, 2008; Triplett et al., 2010; Wallis et al., 2006). The availability of CHO as a substrate for muscles and the central nervous system has not only been identified as a limiting factor for endurance performance it has also been linked to high intensity intermittent exercise (Burke et al., 2001).

2.1.2. The performance effect of CHO supplementation on exercise lasting under 1 hour

Research has demonstrated a positive improvement in performance during steady-state exercise lasting ~1 hour following ingestion of CHO (Anantaraman et al., 1995; Blackhouse et al., 2006; Davison et al., 2008; Below et al., 1995; El-Sayed, Balmer and Rattu 1997; Jeukendrup et al, 1997; Nicholas et al., 1999; Maughen and Poole, 1981).

Interestingly a significant performance effect (3.0% Vs. placebo) was found when participants ingested as little as 25g/h during a 1-hour self-selected time trial (el-Sayed, Balmer and Rattu, 1997). While other studies have failed to find a significant performance effect despite administering greater quantities of CHO (Bonen et al., 1981; Desbrow et al., 2004; Powers et al., 1990). One plausible explanation for the discrepancy amongst the literature is the amount of time CHO was exposed to receptors within the oral cavity.

There have also been an increasing number of studies reporting CHO supplementation has a performance effect in intermittent sports, characterised by bursts of high intensity exercise followed by periods of lower intensity exercise. This is somewhat surprising as performance is not only determined by maintenance of speed and power but factors such as agility, timing, motor skill, and decision making are likely to play a role (Jeukendrup, 2013). Nonetheless research has shown CHO supplementation not only increases performance (Bottoms, Hunter and Galloway, 2007; Davison et al., 2008; Foskett, Williams, Boobis, Tsintzas, 2008; Nicholas, Nuttall, & Williams, 2000; Nicholas et al., 1995; Patterson & Gray, 2007) it also improves skill maintenance (Ali et al., 2007; Ali and Williams, 2009; Curell, Conway and Jeukendrup, 2009; Northcott et al., 1999; McRae and Galloway, 2012; Welsh et al., 2002) especially towards the end of the game.

2.2. Mechanisms of CHO supplementation

CHO supplementation has been associated with a delayed onset of fatigue, and improvements in sport performance in a wide range of sporting activities (Jeukendrup, 2013; Stellingwerff and Cox, 2014). The mechanisms of fatigue are complex and differ depending on the duration of the sport. However it is believed fatigue occurs firstly

within the mind and secondly within the body (Bainbridge, 1919). So the mechanisms and regulations involved in fuel metabolism and energy production during exercise are multifaceted (Stellingwerff and Cox, 2014). Moreover the metabolic and performance effect of CHO supplementation is influenced by a number of factors, including the type and intensity of the exercise, the training status of the athlete and the intake rate of CHO. Nonetheless two primary mechanisms to explain the effect of CHO on performance have emerged from existing research papers. Firstly the direct influence on CHO oxidation (CHO_{oxid}) rates during prolonged exercise (>2 hours) where skeletal muscle and liver glycogen stores are a limiting factor (Cermack and Loon, 2013). Secondly, during exercise lasting under 1 hour there is a central nervous system response to exposure to CHO in the oral cavity.

2.2.1. Proposed mechanisms of CHO supplementation during shorter high-intensity exercise lasting less than 60 minutes

Since the publication of early performance studies it has become scientifically accepted that CHO supplementation can improve endurance capacity (Burke and Maughan, 2015). The performance benefit has been attributed to enhanced maintenance of blood glycogen resulting in augmented CHO_{oxid} by the muscles (Jeukendrup, 2010). It was originally believed CHO supplementation could not improve performance during shorter bouts of exercise (<1 hr.). Theoretically the contribution of blood glycogen to energy expenditure is minimal compared to the high oxidation rates of muscle (Romijn et al., 1993; van Loon et al., 2001). Specifically, during the first hour of exercise only 5-15g of exogenous CHO is oxidized, which is too small to significantly impact performance (Jeukendrup et al., 2010). However practical observations have shown CHO ingestion or CMR improves performance during short and intense exercise (<1 hr.) (Anantaraman et al., 1995; Below et al., 1995; Chambers et al., 2009; Fares and

Kayser, 2011; Gam et al., 2013, Lane et al., 2013; Davison et al., 2008; El-Sayed, Balmer and Rattu 1997; Jeukendrup et al, 1997; Nicholas et al., 1999; Maughen and Poole, 1981; Pottier et al., 2010; Sinclair et al., 2013)

A possible explanation for this contradiction has developed from the observations of Carter et al. (2004a) who found the route of administration of the CHO supplementation to be crucial in determining the performance effect. In particular mouth rinsing a CHO solution, which did not affect blood glycogen levels, was seen to significantly improve 1-hour cycling TT performance (Carter et al., 2004b). This finding lead Carter and colleagues (2004b) to conclude that there are receptors in the mouth, which can influence neural pathways and improve subsequent performance (Chambers et al., 2009). Over the past 20 years there has been increased recognition of the role played by the brain in determining exercise performance (Burke and Maughan, 2015). Neuroimaging studies have found glucose ingestion activates the primary taste cortex and the putative secondary taste cortex in the orbitofrontal cortex (de Araujo et al., 2003; O'doherty et al., 2001). Similarly neuroimaging studies have shown CMR activates the orbitofrontal cortex (Chambers Bridge and Jones, 2009; De Pauw et al., 2015; Turner et al., 2014). Providing preliminary evidence to mechanistically support the practical observations of CMR studies.

2.2.2 The proposed mechanisms of CMR

The first study to investigate the mechanisms of CMR was conducted by Chambers, Bridge and Jones (2009). The researchers used functional magnetic resonance imaging (fMRI) to identify differences in brain regions activated whilst mouth rinsing a solution containing MALT, glucose or an artificially sweetened placebo. Both glucose and the placebo were found to activate the primary taste cortex and dorsolateral prefrontal

cortex. The dorsolateral prefrontal cortex is believed to play a role in the preparation and selection of cognitive responses (Rowe et al., 2000). Both glucose and MALT increased activation of the orbitofrontal cortex, whereas the artificially sweetened solution did not. Increased activation within the orbitofrontal cortex is linked to increased dopaminergic pathways in the striatum. The striatum has been linked to emotional and behavioural responses to reward (Berridge and Robinson, 1998; Kelley et al., 2002; Rolls, 2007). In addition it is associated with arousal, decision-making, reinforcement, motivation and the control of motor behaviour (Berridge and Robinson, 1998; Ferré et al., 2010; Taylor et al., 2013; Yager et al., 2015). The fact that despite varying sweetness both MALT and glucose were shown activate the same regions of the brain following CMR suggest the receptors within the mouth are responding to another property found in natural sugars rather than the sweetness. Similar findings have been reported using electroencephalography (EEG) by De Pauw et al. (2015).

Turner et al. (2014) were the first to investigate the effect of CHO in the mouth on regions of the brain whilst performing a motor task. FMRI was used to measure regions of the brain activated at rest and during a handgrip motor task following mouth rinse of either a CHO solution or taste-matched placebo. The researchers found CHO increased activation within the primary sensorimotor cortex during physical activity and enhanced the neural networks involved in sensory perception (Turner et al., 2014). The neuroimaging studies provide some support for the central response to CHO in the oral cavity, which warrants further research to continue to improve our understanding of how CHO is processed by the brain. While the research has identified regions of the brain activated in response to CHO in the mouth the exact mechanisms of the response remain undefined. Chambers, Jones and Bridge. (2009) speculate the calorific content of CHO rather than sweetness may be responsible for the neural response to CHO in the

mouth although to date there has been no research to confirm this. Also the specific receptors in the mouth that respond to CHO are unknown.

2.3. CMR and exercise performance (lasting ~1 hour)

One recent breakthrough within the scientific literature which is gaining momentum is the effect of CHO supplementation without the need to ingest on exercise performance lasting ~1 hour. Carter et al. (2004a) found that when CHO was infused straight into the bloodstream, bypassing both the mouth and gastrointestinal (GI) tract, then 1h cycling time-trial (TT) performance remained unaltered in comparison to an artificially sweetened placebo (Carter et al., 2004a). Indicating that CHO_{oxid} and muscle glycogen stores were not limiting factors in cycling performance lasting 1 hour. Thus the researchers proposed a central response to CHO, via the brain, was responsible for the performance effect observed during exercise performance lasting ~ 1 hour.

In a follow-up study Carter, Jeukendrup and Jones (2004b) were able to eliminate the effect of the GI tract and CHO_{oxid} rates by developing a mouth rinsing protocol where the participants swilled the solution in their mouth before expectorating it, known as CMR. The study followed a double-blind crossover design, where participants mouth rinsed 25ml of either a 6.4% MALT solution or water (Placebo) every 12.5% during a 1-hour cycling TT. The TT performance was significantly improved by 2.9% ($P=0.003$) in the MALT trial compared to the placebo trial. Several subsequent performance studies have replicated the performance effect of CMR, using cycling (Chambers, Bridge and Jones, 2009; Fares and Kayser, 2011; Lane et al., 2013; Pottier et al., 2010; Sinclair et al., 2013;) and running (Rollo et al., 2008; Rollo et al., 2010) interventions. Moreover a handful of research articles have found a positive effect of CMR on intermittent sport performance (Beaven et al., 2013; Philips et al., 2015; Rollo

et al., 2015). The magnitude and direction of results depend on a number of variables, including the mode and intensity of the exercise, the frequency and duration of mouth exposure, and the nutritional status of subjects (Burke and Maughan, 2015).

2.3.1. The effect of CMR on steady state exercise performance

Cycling is currently the most frequently used intervention in CMR studies. A number of studies have found CMR to significantly enhance performance (Carter Jeukendrup and Jones, 2004b; Chambers Bridge and Jones, 2009; Fares and Kayser, 2011; Kasper et al., 2015; Lane et al., 2013; Pottier et al., 2010; Sinclair et al., 2013) using a range of protocols and differing sweetness of CHO. In a recent meta-analysis pooled from several eligible cycling studies the mean improvement in power output following CMR was ~5 W (95% CI = 0.9-9 W), which is significant both statistically and as an outcome in sporting events (de Ataide e Silva et al., 2014). Moreover CHO was found to significantly improve time to fatigue whilst cycling (60% Max_{watt}) in both a fed and fasted state when compared to placebo (3.5% and 11.6% for fed and fasted respectively) (Fares and Kayser, 2011). Indicating that exposure to CHO in the mouth alone has an attenuating effect on fatigue and therefore performance.

It is important to note that not all the research has reported a significant effect of CMR on steady-state performance lasting ~ 1 hour (Beelen et al., 2008; Che Muhamed et al., 2014; Gam, Guefli and Fournier, 2013; Witham and McKinney et al., 2007). Che Muhamed et al., (2014) found ~ 12% improvement in 10km TT performance when either a water or CHO solution was mouth rinsed for 5 seconds compared to a no rinse protocol in the heat. CHO did not have any additional benefit to performance when compared to mouth rinsing with water alone. It is possible the length of exposure to CHO within the oral cavity may have been insufficient to detect a performance effect.

Sinclair et al. (2013) found although mouth rinsing a CHO solution (6.4% maltodextrin) for 5 seconds improved 1- hour TT performance compared to a taste-matched placebo the difference only reached significant when the participants mouth rinsed CHO for 10 seconds. These findings indicate a potential dose-response relationship between CMR and performance.

Beelen et al. (2008) proposed that the performance benefit associated with mouth rinsing CHO was removed when glycogen stores were full prior to testing. They found no significant difference in 1-hour TT cycling performance between CHO and placebo when participants ingested a high CHO breakfast prior to testing (Beelen et al., 2008). However several observations exist to indicate the nutritional status of participants prior to testing is not a definitive regulator of the effect of CMR. Witham and McKinney (2007) found no effect of CMR on 60-minute TT performance despite an overnight fast whereas Pottier et al. (2010) did find a performance effect when a high-CHO meal was ingested 2 hours prior to testing. Furthermore two recent studies have observed a significant improvement in performance when participants were fed and fasted prior to testing (Fares et al., 2011; Lane et al., 2013). Although a greater increase in 1-hour TT performance was observed in when the participants were fasted prior to testing (1.8% and 3.4% for fed and fasted states respectively) (Lanes et al., 2013).

The effect of mouth rinsing with a CHO solution on steady-state running performance, lasting between 30 and 60 minutes, has also been researched. The first study to investigate the effect of CMR on running performance found no difference in distance covered or rate of perceived exertion (RPE) between trials. Despite following a similar mouth rinsing protocol to previous cycling studies (6% CHO or a placebo solution every 6 minutes throughout a 45-minute TT) (Witham and Mckinney, 2007). The

discrepancy between the findings of Witham and Mckinney (2007) and previous studies reporting a significant improvement in cycling TT performance could be attributed to the mode of exercise used during testing (Rollo et al., 2008). One of the key limitations of the study by Witham and Mckinney (2007) was that running speed had to be adjusted manually. Thus the participants were not able to adjust their speed spontaneously depending on RPE (Lauren et al., 2007; Witham and Mckinnay, 2007). In contrast, power output during cycling can be quickly changed by simply altering pedal cadence.

Subsequent running studies were able to overcome this limitation by using an automated treadmill system (Rollo et al., 2008; Rollo et al., 2010). Rollo et al. (2008) found mean speed recorded during a 30 minute TT was significantly higher in the CHO trial in comparison to the placebo ($P = <0.05$) when participants were asked to self-select a speed based on RPE. Consequently the distance covered was 1.7% further in the CHO trial in comparison to the placebo ($6584 \pm 520\text{m}$ and $6469 \pm 515\text{ m}$ for CHO and placebo respectively). In a follow up study Rollo et al. (2010) reported self-paced 60-minute running performance was improved by 1.5% in the CHO trial compared to the placebo. Therefore it would appear that the performance effect of CMR on cycling TT performance can be replicated in running studies providing runners are able to spontaneously adjust their speed.

2.3.2 The effect of CMR on intermittent sport performance

There have also been a number of studies that have reported improvements during intermittent exercise following CHO supplementation. The effect of CHO on intermittent sport performance has been attributed to a central response (Carter et al., 2004a). Receptors in the mouth responding to CHO activate regions of the brain associated with reward and motivation (Chambers, Bridge and Jones, 2009). Therefore

it could be assumed that the CHO does not need to be ingested in order to elicit a performance effect on intermittent sport performance.

To date the evidence to support the performance effect of CMR during intermittent sport remains inconclusive. A number of research studies have found there is no significant effect of CMR on maximal sprint performance (Chong, Guelfi and Fournier, 2010; Gam, Guefli and Fournier, 2013; Přibyslavská et al., 2015) or repeated sprint ability (Bortolotti et al., 2013; Dorling et al., 2013). Chong, Guelfi and Fournier (2010) found mouth rinsing either a glucose or MALT solution immediately prior to testing did not improve 30-s maximal sprint performance on a cycling ergometer. Likewise, Gam, Geulfi and Fournier (2013) found no significant effect on 30-second maximal sprint performance despite increasing the mouth rinse duration from 5s to 10s. Moreover, repeated sprint (6xsprints with 24s recovery) mean time (3.45 ± 0.2 Vs. 3.44 ± 0.11 ; $p = 0.11$) or fastest time (3.38 ± 0.2 Vs. 3.37 ± 0.2) was not significantly improved by CMR (Dorling, Ernest and Conrad, 2013).

In contrast, Beaven et al. (2013) found sprint performance to be significantly faster in the CHO trial compared to a taste-matched placebo, indicating CMR can have an immediate effect on cycle sprint power production. These findings have been supported by very recently published performance studies (Kasper et al., 2015; Philips et al., 2015; Rollo et al., 2015). Both Phillips et al. (2015) and Rollo et al. (2015) reported a 'likely benefit' (81% and 86% respectively) of CMR on sprint performance using a magnitude of inference analysis. Since the performance benefit of CMR is likely to be small, it is possible the discrepancy between the findings of studies could be due to the sensitivity of the performance test.

Over the past year studies have investigated the effect of CMR on skill maintenance (Clarke, Kornolios and Richardson, 2015; Přibyslavská et al., 2015). However, little or no significant effect on skill-specific performance has been observed. In soccer, Přibyslavská et al. (2015) found no significant improvement in a range of anaerobic performance tasks, including maximal vertical jump and multiple vertical jumps, following multiple CMR in female players. Similarly maximal strength and muscular endurance was not affected by CMR (Clarke, Kornolios and Richardson, 2015). The performance of skills within a sporting context is often referred to as 'open skills' as they incorporate a mixture of cognitive, perceptual and motor processes, in response to external stimuli (Bate, 1996). Therefore developing effective sport-specific protocols to measure skill performance within a laboratory can be challenging (Ali and Williams, 2009). This could explain why there is comparatively less research into the effect of CMR on intermittent skill-based performance in sports including fencing.

In order to fully understand the effect of CMR on skills based performance it is important to investigate whether CHO in the mouth could influence cognitive function. Studies have used a stroop test to measure both accuracy and speed of response to randomised mixture of congruent and incongruent word-colour combinations. Sanders et al., (2012) found mouth rinsing with a glucose solution significantly improved reaction time to incongruent stimuli during a stroop test. They proposed the response was due to increased self-control. Whereas De Pauw et al. (2015) found no significant difference in response time to congruent or incongruent stimuli when a MALT solution was mouth rinsed. It is possible the type of CHO mouth rinsed has an effect on cognitive function. It is also worth noting Meeusen et al. (2015) did not include a fatiguing protocol. Therefore the effect of MALT on cognitive function when participants are fatigued remains unknown.

2.4. Factors Influencing Fencing Performance

Fencing is an open-combat skill based Olympic and Paralympic combat Sport (Bottom, Greenhalgh and Gregory, 2013). An epee fencing competition consists of between 17 and 48 minutes effective fight time spread over a period of 9 to 11 hours. The first round of the competition consists of 5-6 fights; the fight finishes when a fencer reaches 5 hits or when 3 minutes of fencing time has been reached. If the scores are even then a minute of extra time will be given to decide a winner. Following the first round of competition a series of direct elimination fights occur, consisting of up to 15 hits within a maximum time of 9 minutes. As in the first round a minute of extra time will be given to decide a winner if 15 hits have not been achieved.

Fencing encompasses both anaerobic and aerobic energy systems. It is characterised by rapid motor performance, for example an attack, followed by periods of low intensity 'bouncing' movements. Although there has been little research into fencing performance, studies have identified that adequate psychological condition is required to prevent central and peripheral fatigue in fencing (Daya, Donne, & O'Brien, 2002; Roi & Bianchedi, 2008). In particular maintenance of attention and visual perception are crucial for performance (Hijazi, 2013). Previous research has found exposure to CHO in the mouth during physical activity increases activation within the primary sensorimotor cortex, which enhances sensory perception including visual perception (Turner et al., 2014). Therefore it could be speculated rinsing with a CHO solution between fights could improve aspects of fencing performance via enhancing the neural pathways in the brain.

Fatigue is one explanation for overt performance reductions during competitive sport (Noakes, 2000). Fatigue is defined as 'an acute impairment of exercise performance,

which leads to an inability to produce maximal force output, due to metabolite accumulation or substrate depletion' (Meeusen, 2014). Research investigating the influence of cognitive and physiological fatigue on skill-performance, mainly within tennis and cycling, has found that fatigue inversely effects skill-performance (Davey, Thorpe, & Williams, 2002; Hornery et al., 2007; Murray et al., 2001; Royal et al., 2006; Vergauwen et al., 1998). Therefore an epee fencer's responses and subsequent performance could be improved by delaying the onset of fatigue.

CHO supplementation has an attenuating effect on fatigue during both endurance exercise and shorter-high intensity exercise. The effect of CHO on fatigue is dependant on the duration and intensity of exercise. There is mounting evidence to suggest that CHO in the mouth attenuates neural fatigue improving subsequent performance intermittent sport and skill-based tasks. Moreover mouth rinsing with a CHO solution has an attenuating effect on neuromuscular fatigue (Jeffers et al., 2015). In recent years, the recommended method of CHO supplementation during intermittent sport is mouth rinsing (Stellingwerff and Cox, 2014, Burke et al., 2015). Therefore it is relevant both practically and theoretically to investigate the effect of CMR on performance in fencing.

2.5. Practical implications of CMR

CMR has been included in recent nutritional guidelines for short higher intensity exercise (<1 hour) where glycogen is not a limiting factor for performance (Jeukendrup, 2013; Stellingwerff and Cox, 2014). Although in many situations it might be practical to swallow the CHO source, it is now understood this is not necessary to elicit a central effect. There are a number of situations when CHO ingestion might not be desirable, for example athletes following a calorie restricted diet or adopting a 'train low' strategy. CMR may also be employed with individuals or during situations where there is a high

risk of gastrointestinal (GI) distress. Research has shown GI distress is commonplace amongst athletes, with an estimated 20-50% experiencing symptoms during an endurance event (Stuempfle and Hoffman, 2015, van Nieuwenhoven et al., 2004). The symptoms experienced impair performance and ultimately prevent athletes from either finishing or winning events (de Oliveira and Burini, 2014).

Chapter 3 Methodology

3.1. Participants

Eleven experienced fencing participants (minimum of 9 year experience) (three female; eight male; 33.9 ± 14.7 years; body mass 79 ± 16 kg; height 162 ± 54 cm) who were all regularly competing in fencing competitions and training a minimum of twice per week volunteered to participate in the study. All participants completed a physical activity questionnaire to ensure they were healthy and injury free. Participants received information detailing the purpose and nature of the study (appendix 1) and gave written consent prior to participating in the study (appendix 2). The study was granted approval by the University of East London Ethics Committee (appendix 3).

3.2. Procedure

The study followed a single-blind crossover design. The participants visited the laboratory on two occasions separated by a minimum of five days (maximum 10 days separation), and were given either a maltodextrin (MALT) solution (6.7%) or placebo (PLAC) to mouth rinse at regular intervals. Participants were required to fast for a minimum of four hours (maximum fasting period of 7 hours) prior to testing and were asked to replicate their food intake for 48-hours prior to testing. When questioned post-test all the participants reported that they had adhered to these instructions. Care was taken to test the subjects at the same time of day for both visits to avoid interference from differences in circadian rhythms.

3.3. Experimental Trials

Each participant completed two trials involving a fencing specific skill-test and a cognitive function test both before and after completing a fencing fatiguing protocol (Figure 1). All fencers used their own protective equipment and swords, which replicated the full equipment they used when competing. Baseline blood glucose and blood lactate were obtained upon arrival, at the laboratory for each trial followed by a self-directed 5-minute warm-up of moderate intensity, consisting of 2 minutes of jogging, 2 minutes of stretching and 1 minute of footwork.

Following the warm-up participants completed a cognitive function test and skill-test. Further blood glucose and blood lactate measurements were collected via a capillary sampling (20 μ l) at the finger. The fatigue protocol simulated a series of six fights replicating the first round of a standard epee fencing competition (Bottoms et al., 2009). After each fight during the fatigue protocol heart rate (HR) was recorded using a polar heart rate monitor (f51) and ratings of perceived exertion for the sword arm (RPE_{arm}), legs (RPE_{legs}) and total ($RPE_{overall}$) were reported using a 20 point Borg scale (Borg, 1982). The participants mouth rinsed an intervention solution between each fight for 10 seconds before spitting it out into a measuring jug. Blood glucose and blood lactate samples were taken immediately after the total fatigue protocol had been completed followed by the cognitive function and skill tests. The subsequent visit followed the same protocol but the subject was given the alternate solution to mouth rinse.

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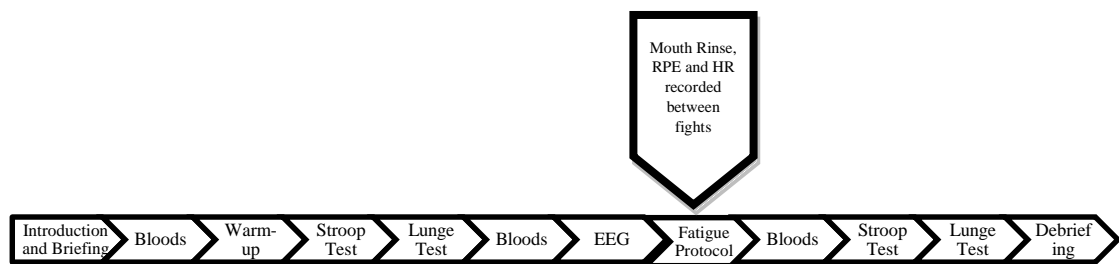


Figure 1. A schematic diagram representing the main study protocol.

3.4. Mouth Rinse Solution and Protocol

Participants mouth rinsed 25ml of 6.7% maltodextrin mixed into water (MALT) or a matched 25ml of Water (PLAC) between each fight during the fatiguing protocol. Participants were asked to swill the solution around their mouth for 10 seconds before spitting the solution out into a measuring jug. The total amount of solution spat out was recorded. At post-test the participants reported they were unable to distinguish between the two solutions.

3.5. Electroencephalography (EEG)

After consent had been obtained and initial blood samples were recorded the participants were asked to be seated and remain as relaxed as possible, at which time two open cup electrodes were placed on the scalp using a conductive gel. The location of the electrodes at Fp1 and F3 was measured using the International 10-20 System. The position of the electrodes measured to ensure they were placed at exactly the same location during both trials. Participants were instructed to close their eyes and relax before mouth rinsing the intervention solution for 10 seconds. The participants opened their eyes to spit out the solution. Participants then remained seated with their eyes

closed for a further 20 seconds. The EEG recordings were taken in a separate section of the laboratory to ensure noise interference was kept to a minimum.

3.6. Cognitive function Test

The participants performed a stroop test consisting of 40 word-colour combinations, both incongruent and congruent (E-Prime 2.08). The first trial also included a practice stroop test consisting of 8 word-colour combinations that served as a familiarisation period. The total response time and accuracy of answers was recorded.

3.7. Skill Test

The skill test comprised of a lunge test to measure accuracy and speed of hits at a target on the chest of a dummy. The target measured 8.9 cm and was centrally located on a fencing dummy. Prior to the test the participants ideal lunge distance was measured and marked from the position of their front foot and remained constant throughout both trials. The participant was instructed to lunge at the target as quickly and accurately as possible for 1 minute replicating an attack in fencing competition. The test is currently used for talent identification by British Fencing so all participants were familiar with the test prior to the trials. A total score of lunges, including hits and misses was recorded. Participants wore their fencing trousers and a t-shirt in addition to their own glove, mask and fencing footwear.

3.8. Fatigue Protocol

The fatiguing protocol replicated a previously validated laboratory based fencing specific protocol (Bottoms et al, 2009). It simulated six poule fights designed to

replicate the first round of poules in a fencing competition. The work-rest ratio was set at 1:0.8 as reported in previously published data (Roi and Biachedi, 2008).

The participant started in the on-guard position facing the fencing dummy. The same starting position was used as employed previously in the lunge test. Participants performed a series of bouncing movements with a standardized number of arm extensions, retreats and lunges for a period of 8 seconds before 9 seconds rest. A full list of the fights can be found in appendix 4. Participants rested for a maximum of 4 minutes between Poules to simulate the rest periods during competition. Participants wore their own protective clothing, glove, mask, fencing footwear and wielded their own sword.

3.9. Data and Statistical Analysis

Blood glucose and blood lactate measurements were obtained from Boisen C-Line Glucose and Lactate Analyser (EFK Diagnostics), which analysed the blood samples. The total number of hits during the test was recorded pre and post protocol for each trial. The accuracy of the lunge test was calculated using the following formula: total number lunges divided by 100 and multiplied by the number of hits on target. Mean Reaction time and total accuracy to both congruent and incongruent stimuli pre and post fatigue protocol for both trials was obtained from E-Prime 2.08. HR and RPE recordings were taken following each fight during the fatigue protocol for both trials.

Statistical analysis of the data was conducted using statistics package for social sciences version 23 for Windows (SPSS, Inc, Chicogo, IL, USA). Blood glucose and lactate,

lunge test accuracy and speed, stroop test reaction time and accuracy, RPE, and HR measurements were assessed using a repeated measures two-way (Treatment X Time) analysis of variance (ANOVA; SPSS v20). Appropriate post hoc analyses were conducted using a Bonferroni correction to control for type I error. In line with the recommendations of Cohen (1988) partial eta squared values of 0.01 were classified as small, effect sizes of 0.06 were classified as moderate and 0.14 or above were classified as large. All analyses were conducted with the significance level set at $p < 0.05$. The data is presented as mean \pm standard deviation in tables and figures.

Chapter 4. Results

Participant characteristics are presented in Table I. Two participants had to withdraw from testing so their data has been excluded from the Table and all subsequent analyses.

Four out of the nine participants were able to correctly identify both solutions post trial. The mean amount of fluid expectorated following the mouth rinse in both trials did not significantly differ from the total amount mouth rinsed ($P > 0.05$). The mean amount of fluid measured at the end of the trial was 136.89 ± 5.53 and 133.33 ± 3.64 ml for placebo (PLAC) and maltodextrin (MALT), respectively.

Table I. Characteristics of the participants (n = 9).

	Age (years)	Height (m)	Weight (Kg)
Mean (\pms)	31.2 (± 14.3)	1.78 (± 0.08)	81.4 (± 16.5)
Range	18-50	167.48-193.04	65-110

4.1. Electroencephalography (EEG)

After a number of pilot tests and experimental trails the decision was made to exclude all EEG data from the experiment. The data could not be analysed correctly due to high levels of interference.

4.2. Blood glucose and lactate

Blood glucose concentrations remained constant throughout both trials, with no significant effect of time ($F(2,16) = 0.712$, $P = 0.5$, $\eta^2_p 0.49$; Figure 2). Blood glucose concentration was not affected by maltodextrin (MALT) with no significant difference observed between trials ($F(1,8) = 0.634$, $P = 0.4$, $\eta^2_p 0.07$), mean concentrations 4.3 ± 0.8 and 4.4 ± 0.8 mmol l⁻¹ for PLAC and MALT respectively. There was a significant effect of time on blood lactate concentrations in both trials ($F(2,16) = 9.35$, $P = 0.002$,

ηp 0.62; Figure 2). Post-hoc analysis showed blood lactate concentration significantly increased ($P = 0.019$; Figure 3) from at rest (1.8 ± 1.7 and 1.2 ± 0.3 mmol l⁻¹ for PLAC and MALT respectively) to pre-fatiguing protocol (4.2 ± 1.5 and 3.7 ± 1.9 mmol l⁻¹ for PLAC and MALT, respectively). However no significant difference was observed between trials ($F(1,8) = 0.123$, $P = 0.7$, ηp 0.01) so MALT had no effect on blood lactate concentrations.

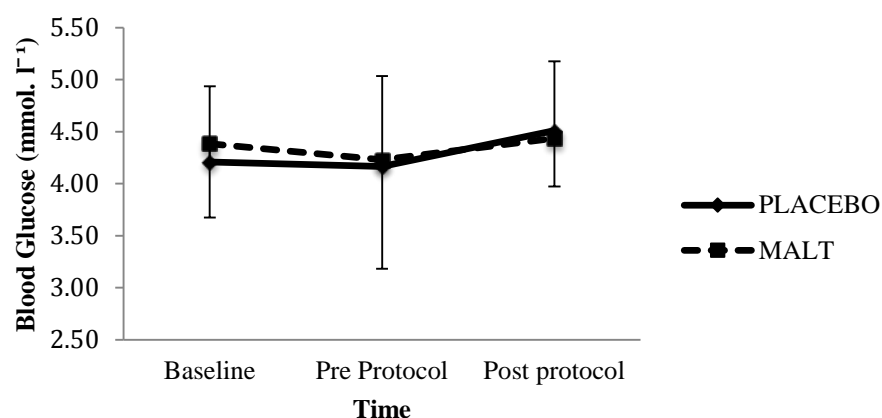


Figure 2. Mean ($\pm s$) blood glucose concentrations during exercise for both placebo and MALT.

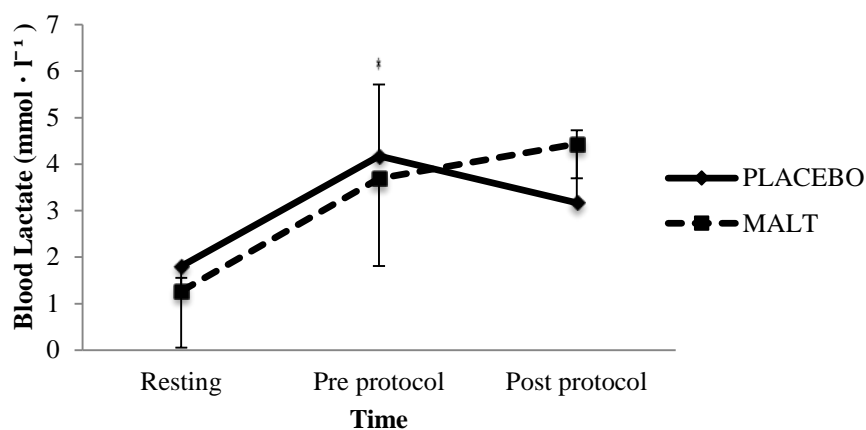


Figure 3. Mean ($\pm s$) blood lactate concentrations during exercise for both placebo (PLACEBO) and maltodextrin (MALT). *Denotes significant increase in blood lactate concentration between resting and pre protocol.

4.3. Perception of exertion and heart rate

The subjects' overall perception of exertion (RPE_{overall} ; 6 to 20 point scale; Borg, 1982) increased throughout the two trials (main effect of time; $F(2,18) = 1.74$, $P < 0.001$, $\eta^2_p 0.85$; Figure 4). Similarly subjects' perception of exertion for the legs (RPE_{legs}) significantly increased over time in both trials (main effect of time; $F(5,40) = 11.564$, $P < 0.05$, $\eta^2_p 0.89$; Figure 4). However subjects' perception of exertion for the sword arm (RPE_{arm}) did not change over time ($F(2,17) = 0.887$, $P = 0.5$, $\eta^2_p 0.0$; figure 4). There was no observed difference throughout testing for RPE_{overall} , ($F(1,8) = 1.174$, $P = 0.310$, $\eta^2_p 0.12$), RPE_{legs} ($F(1,8) = 0.565$, $P = 0.474$, $\eta^2_p 0.06$), and RPE_{arm} ($F(1,8) = 0.001$, $P = 0.981$, $\eta^2_p 0.1$) between trials. The subjects' perception of exertion and heart rate for both MALT and PLAC are presented in Table II. A significant increase in heart rate was observed in both trials between fight 1 and 2, and 1 and 3 (< 0.05 ; figure 5). There was no effect of MALT on heart rate, as no difference was observed throughout testing between trials ($F(1,8) = 0.026$, $P = 0.875$, $\eta^2_p 0.003$).

Table II. Mean ($\pm s$) RPE (Borg Scale) and heart rate during all fights for PLA and MALT trials for sword arm, legs and overall.

	RPE_{arm}	RPE_{legs}	RPE_{overall}	Heart Rate (beats \cdot min ⁻¹)
PLA	10.9 (± 2.3)	13.0 (± 2.4)	13.4 (± 1.4)	158 (± 7)
MALT	10.9 (± 2.5)	12.6 (± 2.8)	12.6 (± 1.8)	159 (± 4)

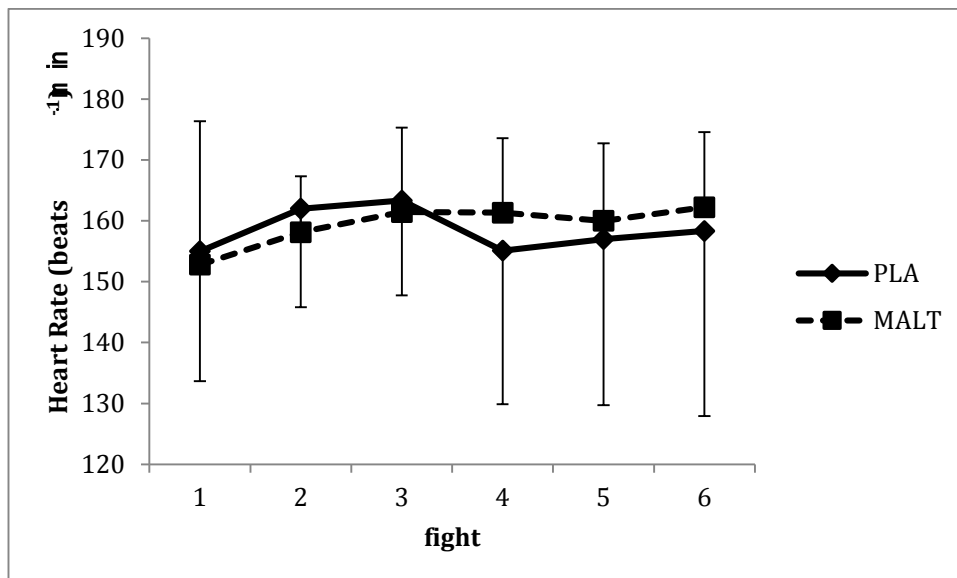


Figure 4. Mean ($\pm s$) heart rate for PLA and MALT.

4.4. Skill test

MALT did not affect total skill test scores, as there was no observed difference between trials, as can be seen in figure 6 ($F(1,8) = 0.302$, $P = 0.6$, $\eta^2_p 0.04$). The mean total number of lunges in both trials increased from 43 ± 12 pre-protocol to 47 ± 15 post-protocol ($F(1,8) = 4.182$, $P = 0.075$). However a significant difference was only observed over time when mediated for trials ($F(1,8) = 5.818$, $P > 0.05$, $\eta^2_p 0.42$). Post-hoc analysis revealed there was a significant increase from 41.9 ± 9.8 to 46.7 ± 12.9 total number of lunges pre-protocol and post-protocol respectively in the PLA trial. However there was no significant increase in total skill test scores in the MALT trial (44.8 ± 9.1 and 46.9 ± 4.5 pre-protocol and post-protocol, respectively). Lunge test accuracy was significantly higher in the MALT trial in comparison to the PLAC ($F(1,8) = 5.214$, $P = 0.05$, $\eta^2_p 0.40$). There was also a large effect size observed, $\eta^2_p 0.40$. Looking at individual results, 7 participants out of the 9 participants accuracy improved post-protocol in the MALT trial, whilst 2 out of the 9 participants accuracy improved post-protocol in the PLAC trial when compared to pre-protocol accuracy percentage.

The mean values of accuracy pre and post protocol for MALT and PLAC are displayed in Table III. The effect of time on accuracy was not significantly different in both trials ($F(1,8) = 0.98$, $P = 0.762$, $\eta^2_p 0.01$).

Table III. The mean ($\pm s$) hits on target (%) for PLAC and Malt.

	Pre protocol (%)	Post protocol (%)
PLAC	82.1 (± 8.8)	78.8 (± 6.4)
MALT	81.2 (± 8.3)	87.6 (± 9.4)

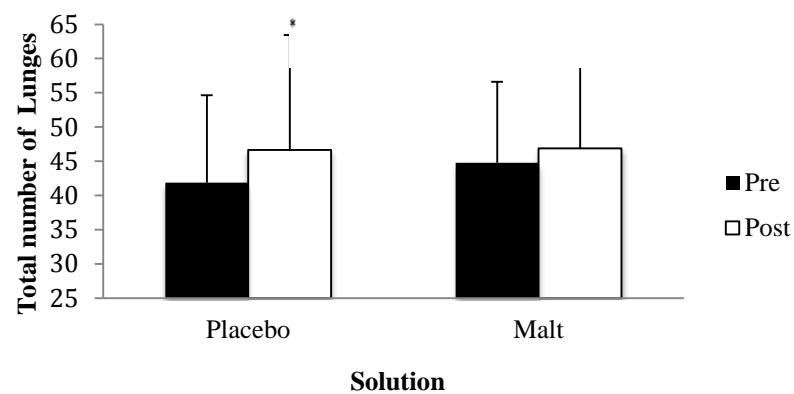


Figure 5. Mean ($\pm s$) number of lunges pre and post fatiguing protocol for placebo and maltodextrin (MALT)

4.5. Stroop test

The response time to congruent stimuli was significantly faster post-protocol compared with pre-protocol in both trials ($F(1,8) = 5.414$, $P = < 0.05$, $\eta^2_p 0.40$). Mean response time were 644.5 ± 83.9 and 593.7 ± 91.5 ms pre-protocol and post protocol, respectively. However there was no significant difference in response time to incongruent stimuli between pre and post protocol in both trials ($F(1,8) = 1.6$, $P = 0.24$, $\eta^2_p 0.17$). Also there was no effect of MALT on response time, as no differences were observed in relation to congruent stimuli ($F(1,8) = 0.326$, $P = 0.58$, $\eta^2_p 0.03$) or incongruent stimuli ($F(1,8) = 0.189$, $P = 0.68$, $\eta^2_p 0.02$) between trials. Figure 7 illustrates the total response time for

both congruent and incongruent questions of the stroop test. The accuracy of the response did not significantly differ throughout this study for both congruent stimuli ($V = 0$, $F(1,8) = 2.485$, $P = 0.15$, $\eta p 0.23$) and incongruent stimuli ($V = 0.089$, $F(1,8) = 0.780$, $P = 0.40$, $\eta p 0.09$). There was also no observed effect of MALT on accuracy for both congruent stimuli ($V = F(1,8) = 0$, $P = 1.00$, $\eta p 0.04$) and incongruent stimuli ($V = 0.037$, $F(1,8) = 0.308$, $P = 0.594$, $\eta p 0.0$).

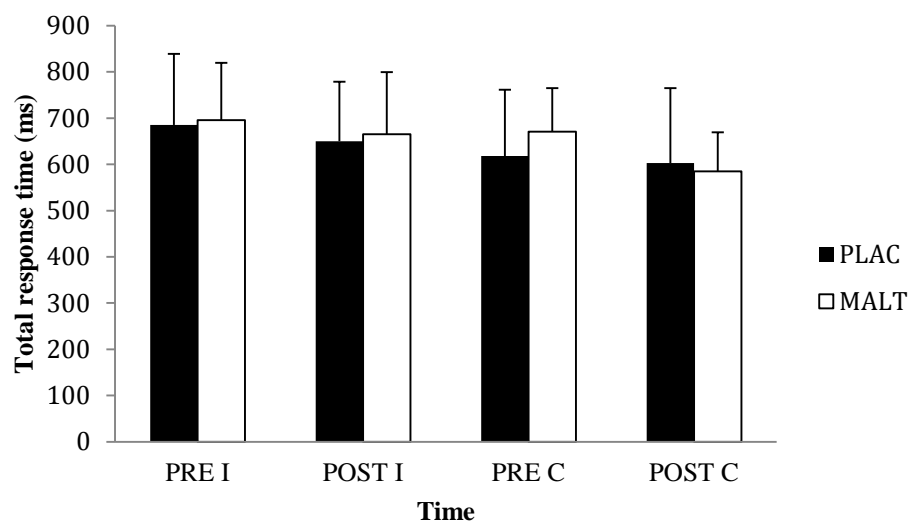


Figure 6. Mean ($\pm s$) pre and post fatiguing protocol congruent (C) and incongruent (I) response times to the Stroop test for both placebo (PLAC) and maltodextrin (MALT).

Chapter 5 Discussion

The aim of the present study was to investigate the effect of carbohydrate mouth rinsing (CMR) on cognitive function and skill-specific performance following a fatigue inducing fencing protocol on epee fencers. A lunge test was used to measure the skill-specific performance of the fencers and a stroop test was used to measure cognitive function. It was hypothesised CMR would improve cognitive function and skill-specific performance. There was a significant improvement in accuracy during the lunge test in the maltodextrin (MALT) trial compared to the placebo ($F(1,8) = 5.214$, $P = 0.05$, $\eta^2 0.4$). However there were no significant differences in the speed or accuracy of the response to congruent ($F(1,8) = 0.326$, $P = 0.58$, $\eta^2 0.04$, and $F(1,8) = 0$, $P = 1.00$, $\eta^2 0.00$ for speed and accuracy respectively) or incongruent stimuli ($F(1,8) = 0.189$, $P = 0.68$, $\eta^2 0.02$, and $F(1,8) = 0.308$, $P = 0.594$, $\eta^2 0.04$ for speed and accuracy respectively). Indicating that mouth rinsing a carbohydrate (CHO) solution may not be enough to affect cognitive function.

5.1. Strengths and limitations of the study

The physiological findings in the present study indicate that a suitable protocol was utilised to fatigue the participants. The results demonstrated a significant effect of time on ratings of perceived exertion (RPE) overall ($F(2,18) = 1.74$, $P < 0.01$, $\eta^2 0.86$) and the legs ($F(5,40) = 11.564$, $P < 0.05$, $\eta^2 0.89$), which provides support for the validity of the fencing fatigue protocol utilised in this study. Moreover mean heart rate recorded post fight 6 in the fencing protocol reached 162 ± 12 beats/min which is similar to the heart rate ranges recorded during an epee competition (Li et al., 1999). The changes in blood glucose, blood lactate, ratings of perceived exertion (RPE), and heart rate were all consistent with the findings of previous studies that have reported a significant

ergogenic effect of CMR on performance. In particular there was no reported differences in RPE or heart rate between the CHO trial and the placebo ($V = 0.003$, $F(1,8) = 0.026$, $P = 0.875$). Furthermore no differences were observed pre-protocol for the lunge skill test or cognitive function test between trials. Indicating the participants were suitably familiarised with the protocol as no learning effect was observed. Thus the likelihood of any performance effect observed was due to the administration of different mouth rinsing solutions.

The results of the present study are consistent with a number of studies, which have observed a significant performance effect when mouth rinsing with a CHO solution (Beaven et al., 2013; Carter, Jeukendrup and Jones, 2004b; Chambers Jones and Bridge, 2009; Fares and Kayser, 2011; Kasper et al., 2015; Lane et al., 2013; Pottier et al., 2010; Rollo et al., 2008; Rollo et al., 2010; Sinclair et al., 2014; Wright and Davison, 2013). However not all of the studies have found a significant effect of CMR on performance (Beelen et al., 2009; Clarke, Kornolios and Richardson, 2015; Gam et al., 2013; Přibyslavská et al., 2015; Witham and McKinney, 2007). The magnitude and direction of the effect of CMR are influenced by a number of variables, including training status of the participants, frequency and duration of the mouth rinse, nutritional status of the participants prior to testing and the mode of exercise. Therefore it was important the present study controlled these variables to avoid any limitations highlighted from previous studies.

The importance of the mouth rinse duration was identified by Sinclair et al., (2014) who observed a potential dose-response effect of CMR on 1-hour cycling time trial (TT) performance. The results showed a significant improvement in TT performance when the participants mouth rinsed with a CHO solution compared to a placebo, but the

improvement only reached significance when the solution was rinsed for 10 seconds. In the present study, the oral exposure to the CHO solution was standardised between trials, i.e., each solution was held in the mouth for 10 s before being expectorated. Therefore the duration of the mouth rinse was adequate to elicit a performance effect. Moreover the present study included multiple mouth rinses (n=6), consistent with the number of mouth rinses utilised in previous studies that have reported a significant effect of CMR on performance.

The nutritional status of the participants prior to testing has a mediating effect on the magnitude of results. The present study included a fasting period (> 4 hours) prior to testing, which is consistent with previous studies reporting a positive effect of CMR on exercise performance (Carter Jeukendrup and Jones, 2004b, Chambers, Bridge and Jones, 2009., Rollo et al., 2008). Overnight fasting increases the cortical response to CHO in a number of brain regions, including the ventral striatum (Haase et al., 2009). Beelen et al., (2009) suggested overnight fasting reduces the validity of the results as in a practical setting athletes typically ingest a high-CHO meal 2 hours prior to competition. They found that CMR did not significantly affect performance when participants ingested a High-CHO breakfast prior to testing (Beelen et al., 2009). However two subsequent studies have reported a significant increase in TT performance when participants mouth rinsed with a CHO solution irrespective of nutritional status (Fares et al., 2011; Lane et al., 2013). Although the increase in 1-hour TT performance in the CHO trial compared to the placebo was greater when the participants were fasted (1.8% and 3.4% for fed and fasted states respectively) (Lanes et al., 2013). It would be interesting therefore to investigate whether the improvement in accuracy observed in the present study could be found when participants were in a fed state.

The present study is the first to observe a significant improvement in skill-specific performance following CMR. Much of the research reporting a significant effect of CMR on exercise performance has measured steady-state performance (Carter et al., 2004b; Chambers et al., 2009; Fares and Kayser, 2011; Kasper et al., Lane et al., 2013; Pottier et al., 2010; Sinclair et al., 2014). Whereas previous studies investigating the effect of CMR on skill-specific performance have observed no significant differences (Clarke, Kornolios and Richardson, 2015; Přibyslavská et al., 2015). Although it is unclear why previous studies measuring the effect of CMR on skill-specific sport performance have failed to reach statistical significance it is possible the measurements were not sensitive enough to detect the small effect of CMR. The reported performance effect of CMR on performance is between 1.5 and 3.5% therefore the measurements used in testing must be sensitive enough to detect an effect. In order to overcome this limitation the present study reduced the target size to a standardised circle (8.9 cm diameter) during the lunge test, even though the whole body is a valid target during epee fencing.

A number of the early mouth rinsing studies have been criticised for not sufficiently masking the CHO solution. As the benefit of CHO supplementation is widely accepted it is possible a 'placebo' effect could occur if the participant could identify the correct solution during testing. Consequently Carter, Jeukendrup and Jones (2004b) could not exclude the potential of a 'placebo' effect on the findings as 6 out of 11 participants correctly identified the solution. While in the present study 4 participants were able to correctly identify the solution post testing, indicating no 'placebo' effect had influenced the results. Witham and McKinney (2007) reported only 1 participant was able to identify the correct solution when a bitter solution was added to both solutions. The inclusion of a bitter solution was not deemed necessary in the present study as pilot

testing showed individuals were unable to detect a difference between solutions. However in subsequent studies it would be recommended to include the bitter solution in order to reduce the number of participants correctly identifying the solutions.

The present study did not include a no rinse protocol, which, is consistent with previous mouth rinsing studies (Carter, Jeukendrup and Jones, 2004; Chambers, Bridge and Jones, 2009; Pottier et al., 2010; Rollo et al., 2010; Rollo et al., 2008; Sinclair et al., 2014). It is possible repeated mouth rinsing during exercise could be detrimental to performance, for example it could interference with the athlete's breathing cycles. Gam et al., (2013) found time to completion was faster in both the CHO (65.7 ± 11.07 min) and no rinse (67.6 ± 12.68 min) trials in comparison to the placebo (69.4 ± 13.81 min; $p = .013$ and $p = .042$, respectively). But in the present study the mouth rinse was administered at rest, so it was not deemed necessary to include a no rinse protocol

5.2 The effect of CMR on skill-specific performance following a fatigue inducing simulated bout of fencing

Fencing is a highly intermittent sport with bursts of very high intensity exercise followed by periods of relatively low intensity recovery. The performance in fencing is dependent on factors other than maintenance of speed and power. It is likely agility, timing, decision-making, motor skill and visual perception all play a vital role in performance. Therefore it is difficult to observe and measure skill-specific fencing performance. Likewise, researchers have identified problems developing skill-specific measurements in football due to the multi-factorial nature of performance (Bate, 1996). Nevertheless the present study found a significant improvement in accuracy and large effect size during the lunge test following multiple mouth rinses with a MALT solution ($F(1,8) = 5.214$, $P = 0.05$, $\eta^2_p 0.40$). Moreover looking at the individual results, 7 out of

the 9 participants accuracy improved during the MALT trial, while just 2 participants showed improvements in the placebo trial. The results of the present study are consistent with a number of studies that have observed CHO ingestion can improve intermittent running capacity (Davison et al., 2008; Nuttall and Williams, 2000; Patterson and Gray, 2007) and skill-specific performance (Ali et al., 2007; Ali and Williams, 2009; Curell, Conway and Jeukendrup, 2009; Northcott et al., 1999; McRae and Galloway, 2012; Welsh et al., 2002).

The present study also aimed to investigate the effect of CMR on fatigue and subsequent skill-specific performance. An increase in heart rate and RPE was observed in both trials indicating that the participants were suitably fatigued by the fencing protocol. Which was reflected by the observed decrease in accuracy post-protocol in the placebo trial (3.4%). However in the MALT trial accuracy improved by 7.7% indicating that adding MALT to the mouth rinsing solution altered the participants fatigue. The findings of the present study provide some support for the effect of CHO within the oral cavity on the development of central fatigue. Fatigue is defined as 'an acute impairment of exercise performance, which leads to an inability to produce maximal force output, due to metabolite accumulation or substrate depletion' (Meeusen, 2014). Peripheral fatigue appears when the energy stores become depleted and an accumulation of by-product impairs muscle contraction, but it cannot explain all the symptoms associated with a performance decline in sport.(Poole et al., 2008; Keyser, 2010). The central nervous system (CNS), which integrates input from the body, also plays an important role, this is known as central fatigue (Grillner., 1997; Jahn et al., 2004; 2008). In particular, higher-level centres in the brain are responsible for the initiation of movement, including speed and direction (Grillner, 1997). Exercise-induced changes in the concentrations of monoamines serotonin and dopamine

neurotransmitters have been linked to central fatigue (Acworth et al., 1986; Newsholme et al., 1987). Studies investigating brain activity following the ingestion of a bolus of glucose (de Araujo et al., 2003; O'doherty et al., 2001) and research demonstrating the activation of several brain regions after rinsing carbohydrate solutions within the mouth (Chambers et al., 2009; De Pauw et al., 2015) have provided some support for the effect of central effect of CHO.

5.3. The effect of CMR on cognitive function following a simulated bout of fencing

The movements within fencing require co-ordination of the upper and lower limbs in order to react to the information given by their opponent. Fencing coaches have previously identified the quickness of a fencers movements in response to their opponents action is crucial for success (Roi and Bianchedi, 2008). Specifically research has identified the importance of visual perception in determining fencing performance (Hijazi, 2013). CMR has been shown to activate regions within the brain, which could improve visual perception (Turner et al., 2014). Therefore investigating the effect of CMR following a fatigue inducing fencing protocol on cognitive function would be beneficial to performance. In particular a generic reaction time test, such as the stroop, could be used to identify the potential benefit of CMR to fencing performance.

The present study failed to find a significant effect of rinsing with a MALT solution on reaction time to congruent ($F(1,8) = 0.326$, $P = 0.58$) or incongruent stimuli ($F(1,8) = 0.189$, $P = 0.68$). There are a number of possible explanations for the lack of significance observed. Firstly the results could indicate mouth rinsing with a MALT solution alone does not affect cognitive function. The findings of the present study are consistent with De Pauw et al., (2014) who also found mouth rinsing with a MALT did not significantly affect reaction time to both congruent and incongruent stimuli ($P >$

0.05) despite increasing activation within orbitofrontal cortex. Whereas Sanders et al. (2012) reported a significant reduction in reaction time to incongruent stimuli during the glucose trial in comparison to the placebo ($P < 0.05$). The discrepancy between these studies could be due to the type of CHO, indicating that glucose and MALT have different effects on cognitive function. It is also possible the extent of fatigue induced by the fencing protocol was not adequate to establish a performance effect of CMR. A performance effect may be established during the latter stages of competition, however more research is needed to confirm this assumption. Finally previous studies have identified differences in reaction time depending on level of fencing experience utilising isolated touché, isolated lunge and sequential lunge and touché in response to light triggers (Harmenberg et al., 1991; Roi and Bianchedi, 2008; Williams and Warmesley, 2000; Yiou and Do, 2000). While this was not deemed necessary for this study, as all the participants were of a similar fencing ability, a fencing specific reaction time test could be developed for future research.

5.4. Future implications and further research possibilities

The present study adds to the current body of research into the effect of CMR on sporting performance. The effect of CMR on steady state performance has been well researched and there is convincing evidence to indicate rinsing the mouth with either a glucose or MALT solution could significantly improve performance by 1.5-3.7% (Beaven et al., 2013, Carter, Jeukendrup and Jones, 2004; Chambers, Bridge and Jones, 2009; Fares and Kayser, 2011; Kasper et al., 2015; Lane et al., 2013; Pottier et al., 2010; Rollo et al., 2008; Rollo et al., 2010 Sinclair et al., 2014; Wright and Davison, 2013). This study presents the first observation that CMR can significantly improve skill-specific performance ($F(1,8) = 5.214$, $P = 0.05$) thus serving to increase the scope of CMR. It would be beneficial for additional research to include a larger cohort of

participants, to improve the statistical power of the results. The findings of the present study warrant further investigations into the possible effect CHO in the mouth can have within skill-based sports. Moreover further research should aim to identify the mechanisms to explain the effect of mouth rinsing with MALT has on intermittent sport performance.

The mechanisms of the response to CHO in the mouth have been partially supported by observations from neuroimaging studies, which have investigated regions of the brain activated during mouth rinsing (Chambers, Bridge and Jones, 2009; De Pauw et al., 2015). These studies observed an immediate increase in activation of the orbitofrontal cortex, when CHO was present in the mouth. The orbitofrontal cortex has been associated with increased reward and motivation, which could explain subsequent performance benefits observed following CMR (Chamber, Bridge and Jones, 2009). Whilst it is known the receptors in the mouth are sensitive to CHO independently of sweetness, the property within CHO responsible for the increased activation has yet to be identified. In addition the specific receptors in the mouth activated by CHO are unknown. So there are still a number of areas yet to be explored in order to enhance our understanding of the mechanism of CMR.

The findings of the present study are not only statistically significant but also important within a practical setting. Looking at the individual results 7 out of the 9 participants lunge test accuracy improved post protocol in the MALT trial. Moreover accuracy was improved 7.7% in the MALT trial, which is substantial in terms of performance. In comparison, accuracy decreased by 3.3% in the placebo trial. Therefore mouth rinsing a MALT solution between fights during the first round of an epee fencing competition could significantly improve performance during the direct elimination round. Based on

the findings of the current study it would be recommended the athlete rinses the mouth with a solution containing 6.7% MALT for a minimum 10 seconds to improve performance. The practical implication for fencing based on the results of the study is that rinsing the mouth with a MALT solution during rest periods between fights could be utilised as a strategy to improve accuracy, especially in the latter elimination rounds of the competition where the onset of central fatigue is likely to occur.

Further research should aim to explore the influence of a higher concentration of CHO solution or a longer duration of mouth rinse on fencing performance. Moreover it would be beneficial to investigate whether the performance effect of CMR in the fed state observed within previous studies (Lane et al., 2013; Fares et al., 2013) could also be established within fencing. Although there are areas yet to be investigated, which could improve the recommendation for using mouth rinsing during competition, the results from this study indicate the possibility of CHO within the oral cavity to improve fencing performance. In many situations it might be practical to ingest CHO the present study indicates it is not necessary to gain a performance effect. The strategy would be particularly useful for athletes who experience gastrointestinal discomfort during competitions or those following a calorie restricted diet.

Chapter 6. Conclusion

In conclusion rinsing the mouth with a carbohydrate (CHO) solution before expectorating it improves skill-specific fencing performance but not cognitive function following a simulated fencing fatigue protocol. The study found lunge test accuracy was significantly higher in the MALT trial compared to the placebo trial. However, mouth rinsing with a MALT solution had no effect on reaction time to incongruent or congruent stimuli during the stroop test compared to a taste-matched placebo.

The results of the study indicate that mouth rinsing with a CHO solution has an attenuating effect on fatigue. In the placebo trial accuracy of the lunges was decreased by 3.4% but in the MALT trial accuracy improved by 7.7% following the fatigue inducing fencing protocol. This is consistent with another report that carbohydrate mouth rinsing (CMR) significantly increased time to exhaustion, i.e. fatigue, during a steady-state cycling trial. It is likely the attenuating effect of CMR on fatigue, and thus subsequent performance effect is due a central nervous system response. In the study blood glucose levels remained unchanged by time in both trials, indicating the CHO from the mouth rinse did not enter the blood stream. Moreover the amount of fluid expectorated post trial did not significantly differ from the total amount of solution mouth rinsed, indicating no fluid was ingested during the trial. Therefore, the improvement in accuracy can be attributed to receptors in the mouth responding to CHO within the oral cavity and subsequently activating regions of the brain. Previous studies investigating the central effect of CHO within the mouth, have found increased

activation in regions of the brain associated with reward, motivation and motor control. There is also evidence CHO in the mouth improves self-control via a central governance in the brain. In terms of the present study it is possible the brain signalled for the individual to reduce the number of lunges in order to improve accuracy in the MALT trial but not in the placebo. This could explain why a significant increase in total number of lunges was observed in the placebo trial following the fatiguing protocol but not in the MALT trial. While neuroimaging studies have identified the regions of the brain activated in response to CHO the exact receptors and responses remain unclear, thus further research is needed to explore the mechanisms of mouth rinsing.

Based on the findings of the present study CMR does not affect cognitive function following a fatigue inducing fencing protocol. The findings showed an increase in reaction time to both congruent and incongruent stimuli. The participants sacrificed speed in an attempt to maintain accuracy, which indicates that some level of central fatigue occurred during both trials, although it was not sufficient to significantly hinder cognitive function. This could explain the failure of CMR to have an effect on reaction time. Therefore it would be interesting to investigate whether a performance effect could be established during the latter stages of competition. Also future research should focus on developing a fencing specific reaction time measurement, which is likely to be more sensitive to detect an effect of mouth rinsing.

The findings of the present study add to the literature supporting a significant effect of rinsing the mouth with a CHO solution before expectorating it on sport performance. It is the first study to observe a significant effect of mouth rinsing with a CHO solution on skill-specific performance. Providing the basis for additional research into the effect of

CHO on intermittent sport performance and skill maintenance. The findings of the study are consistent with previous studies that have found ingesting CHO can improve skill maintenance and performance. However it is the first study to indicate it is not necessary to ingest the CHO to improve performance. Providing partial support that the performance benefit observed following CHO supplementation during intermittent sport and skill-specific tasks can be attributed to a central response rather metabolic changes. Future research should aim to investigate the exact mechanisms of CMR during skill-specific tasks and intermittent tasks, by examining regions of the brain activated following exposure to CHO in the mouth.

The results of the study are significant statistically and as a practical performance outcome. Looking at individual results 7 out of the 9 participants accuracy improved following CMR while only 2 participants accuracy improved in the placebo trial. The fatiguing protocol utilised in the study simulates the first round of an epee fencing competition. So mouth rinsing with a carbohydrate solution throughout the first round of competition can improve accuracy within the later elimination rounds of the competition, which could alter the outcome of the competition. The challenge remains how the mouth rinse would be administered during an epee fencing competition in order to comply with the rules and regulations of competition. The study does not provide evidence against ingesting the CHO solution following a 10 second mouth rinse, but rather highlights the importance of exposure to CHO within the oral cavity. Furthermore it highlights that it is not necessary to ingest CHO during fencing to elicit a performance effect. This may be particularly important for athletes who experience symptoms of gastrointestinal distress or those following a calorie restricted diet.

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Appendices

Appendix 1. Information sheet for participants

INFORMATION SHEET FOR PARTICIPANTS

Programme of Study: MRes Sport Science.

Title of Project: The effect of carbohydrate mouth rinsing on fencing performance and cognitive function following a fatigue inducing simulated bout of fencing in national level fencers.

Dear Participant,

You are being invited to take part in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and ask if there is anything that is not clear or you would like more information on. Please take time to decide whether or not you wish to take part.

What is the purpose of the study?

It has been documented that due to increased demands for energy when exercising, carbohydrate supplementation during sport can enhance performance. Over the last ten years, research has been carried out to assess the effect of carbohydrate ingestion during exercise across many different sports. Research has found a positive outcome on delaying fatigue, decreasing perceived exertion and decreasing the rate of skill deterioration.

Although the ingestion of carbohydrates during exercise have been found to have an advantage on sport performance, side effects such as bloating, stomach ache, nausea and intestinal cramps have been experienced raising several disadvantages for ingesting carbohydrate during exercise. To combat this, recent studies have found that carbohydrates do not actually have to be consumed in order to have an effect on performance and mouth rinsing a carbohydrate solution can be just as effective on sport performance. Currently, no research has been carried out on the effect of mouth rinsing in fencing and thus, the aim of this study is to investigate the effect of carbohydrate mouth rinsing and a matched placebo solution on fencing skill performance and cognitive function following simulated bout of fencing.

In order to carry out this study, 10 fencing athletes will need to be recruited. All participants must be recreationally active aged over 16 years with a minimum training status of one day a week. Participants can only take part in the study after the completion of a PAR-Q showing no risks and have no injuries.

What will I have to do if I take part?

If you decide to take part in this study it will consist of 2 trial days lasting roughly 2 hours separated by a minimum 48 hours. In order to standardise testing, you will be required to record a 48hr food and drink diary before the first trial and replicate your intake for the second and third trial days ensuring you fast for the final 2hrs before both trials. The overall design of the study is composed of three phases. The first will consist of fencing-specific skill tests (lunge test) and a measurement of cognitive function (Stroop Test). The second phase is a simulated fencing bout, consisting of 6 fights designed to replicate the real demands of competition. Between each fight the participant will be required to mouth rinse 25ml of maltodextrin (6 % carbohydrate) solution or a matched to taste placebo. Blood lactate tests using finger pricks will be completed before and immediately after the simulated bout for analysis in changes of blood lactate. In order to monitor your safety, rate of perceived exertion will be monitored during mouth rinsing intervals using the Borg scale and heart rate will be monitored every five minutes. The final phase will consist of repeating the fencing-specific skills test and cognitive function test providing the comparative. On the second trial day the same procedure will be followed but the participant will be given a different solution.

All trial days will take place at SportsDock.

What are the possible advantages of taking part?

By taking part in this study you will be helping generate brand new research which if carbohydrate mouth rinsing is found to make a positive difference can benefit your future fencing performance.

What are the possible disadvantages or risks of taking part?

You will be required to exercise to near maximum capacity as though you are competing in fencing under natural conditions but will not be required to exercise at intensities higher than experienced in a normal fencing bout. Heart rate and perceived exertion will be monitored and withdrawal will occur if it is believed you are working beyond levels which are deemed to be safe.

Blood samples will be taken twice per trial day and may cause bruising to the fingertip but will not cause a need for concern. To prevent this you will be required to apply pressure to your fingertip after sampling.

Do I have to take part?

You are under no obligation to participate in this study. If you do decide to take part, you are free to withdraw at any time without giving a reason. If you do not take part, or withdraw from the study at a later date, it will not disadvantage you.

What will happen to the information?

Your participation in this study and all information collected will be kept strictly confidential. Where necessary, information collected will be coded so that you cannot be recognised from it. The results of this study will be reported as part of my degree programme and may be further disseminated for scientific benefit. The results will be available to you on request.

Who should I contact for further information or if I have any problems/concerns?

Researcher:

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Supervisor:

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Lindsay Bottoms

L.bottoms@uel.ac.uk

Appendix 2. Written consent form

Written Consent Form

Have you been given a copy of the information sheet to keep?	Yes/No
Do you understand the details provided in the information sheet and feel sufficiently informed?	Yes/No
Have you been given the chance to talk about the study and ask questions?	Yes/No
Do you understand the procedures and time involved in this study?	Yes/No
Have you been given the information and do you understand the risks involved in participating?	Yes/No
Have you recently (past 1 month) been involved or are simultaneously involved in another research study?	Yes/No
Have you been informed of the confidentiality procedures and do you accept them to be adequate?	Yes/No
I understand that my personal information may be stored on a computer. If this is done then it will not affect the confidentiality of this information. All such storage of information must comply with the 1998 Data Protection Act.	Yes/No
Do you consent to taking part in this study?	Yes/No
Are you aware of your right to withdraw from the study at any time without having to give reasons?	Yes/No
Do you know whom to contact if there are problems?	Yes/No

Participant Name: (block capitals)

Participant signature:

Date:

Investigator name: (block capitals)

Investigator signature:

Date:

EXTERNAL AND STRATEGIC DEVELOPMENT SERVICES

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Quality Assurance and Enhancement



I am pleased to confirm that the approval of the proposed research applies to the following research site.

Approved Documents

The final list of documents reviewed and approved by the Committee is as follows:

<i>Document</i>	<i>Version</i>	<i>Date</i>
UREC application form	1.0	06 May 2015
Participant information sheet	1.0	06 May 2015
Consent form	1.0	06 May 2015

Research Site	Principal Investigator / Local Collaborator
SportsDock, UEL Docklands Campus	Dr Richard Buscombe

Approval is given on the understanding that the [UEL Code of Good Practice in Research](#) is adhered to.

Please note, it is your responsibility to retain this letter for your records.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Rosalind Eccles

University Research Ethics
Committee (UREC) UREC Servicing
Officer

Email: researchethics@uel.ac.uk

Appendix 4. Fencing fatigue protocol

Fight 1	On	Off	Lunge	Retreat	Arm
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	1	2
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	1	2
	8	9	1	0	2

Fight 2	On	Off	Lunge	Retreat	Arm
	8	9	1	0	3
	8	9	1	1	2
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	1	2
	8	9	1	0	2
	8	9	0	0	2
	8	9	1	1	2

Fight 3	On	Off	Lunge	Retreat	Arm
	8	9	1	0	2
	8	9	1	0	3
	8	9	1	1	2
	8	9	1	0	2
	8	9	1	1	2
	8	9	1	0	2
	8	9	1	0	2

Fight 4	On	Off	Lunge	Retreat	Arm
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	1	3
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	1	2
	8	9	1	0	2

Fight 5	On	Off	Lunge	Retreat	Arm
	8	9	1	1	2
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	0	2
	8	9	1	0	2
	8	9	0	1	2
	8	9	1	0	2

Fight 6	On	Off	Lunge	Retreat	Arm
	8	9	1	0	2

8	9	1	0	2
8	9	1	1	2
8	9	1	0	2
8	9	1	0	3
8	9	1	0	2
8	9	1	1	2
8	9	1	0	2